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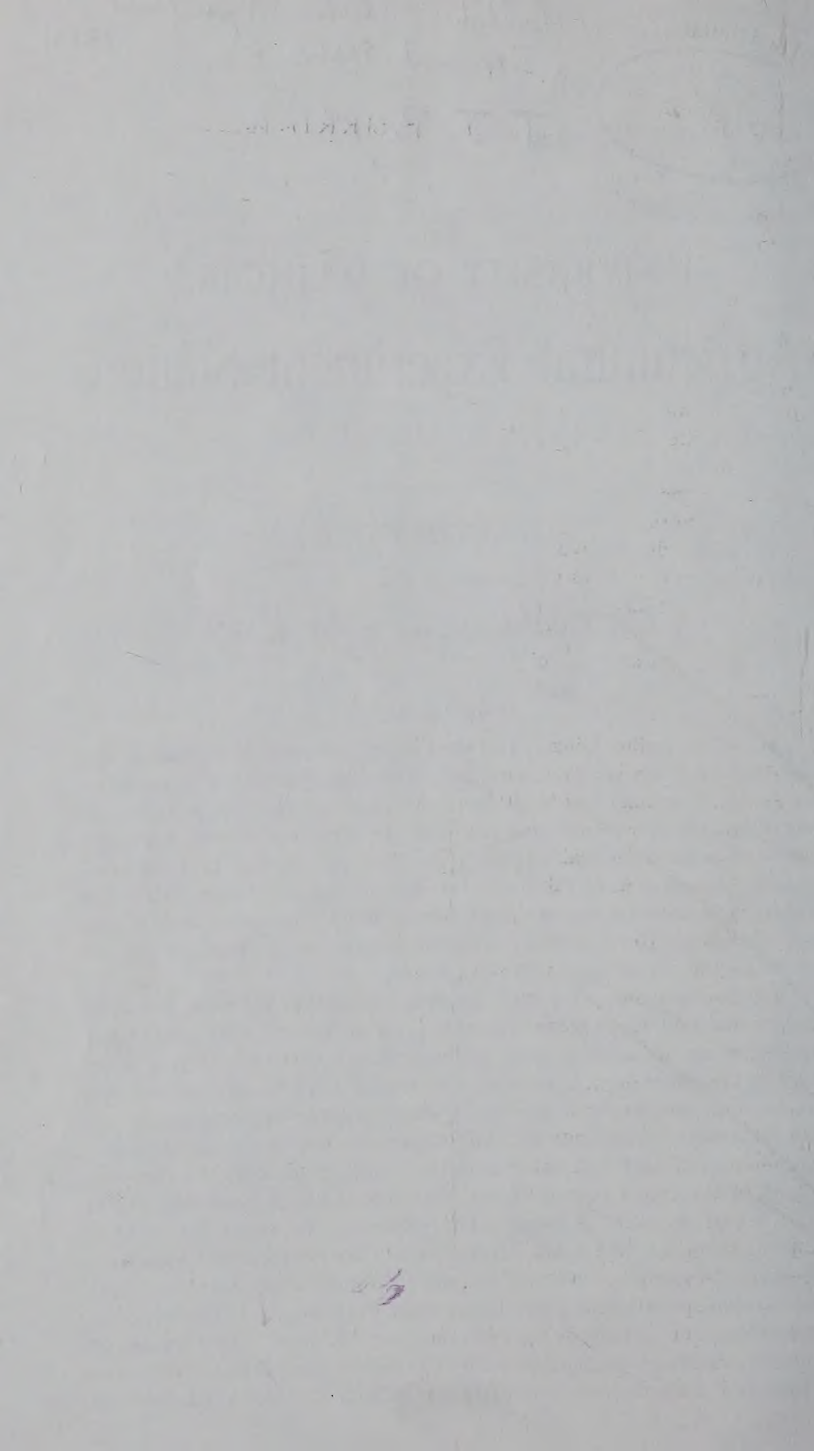
BULLETIN NO. 6.

A BACTERIAL DISEASE OF CORN.

INTRODUCTORY.

Maize, or Indian corn, is the most important crop throughout a very large portion of the United States, and so any injury whatever to the plant is a matter of serious concern. In the whole range of the vegetable kingdom there are few plants that can compare with it in normal vigor and abundant general productiveness. No other agricultural crop so dominates the appearance of the fields throughout the great corn belt in our country, and none returns to the pockets of the producers so large a total sum of cash. "Corn is king," and apparently must remain so in the political economy of our part of the world.

To those who have made themselves acquainted with the prevalent diseases and injuries of other vegetable productions and who reflect upon the vast areas annually planted to corn, often successively during many years on the same land, it must be a matter of supreme satisfaction that this magnificent staple so far, to an exceptionable degree, escapes the harmful attacks of vegetable and animal parasites and the destructive ravages of larger insect and other animals. Still, because of the immense amount of the cereal produced, the total annual losses from such causes make a vast financial showing. The entomologists count insect pests injurious to corn by the score, some of which are charged with enormous aggregate destruction. No one has more carefully studied or more fully made known these insect depredators than Professor S. A. Forbes, State Entomologist of Illinois, as his published reports show. In a lecture on "Insects Affecting Corn," delivered by him before many farmers' institutes in Illinois, during the last half-dozen years, he has brought together and



presented in a popular manner the existing information upon the subject, with enlarged illustrations of several species and representations of their work.

Besides the destruction by insects, there is known to be considerable loss from fungous parasites. Among these the best known is "smut,"—the great sooty masses that form on any part of the plant above ground, but very commonly on the ear, which the fungus more or less displaces by its own unsightly production. This smut is a vegetable parasite. It sends its delicate fibres—much too fine to be seen with the unaided eye—through and through the tissues of the stalk, beginning when the latter is very young, and finally forms its abundant mass of black spores in the swollen projections so well recognized by every one. These sooty spores are the germs for the next year's smut, enough of them lasting over winter to perpetuate the fungus. There is also a rust upon the leaves of corn quite similar to that known by the same name on wheat, but comparatively much less destructive. This, too, is a fungus, growing in the tissues and living upon the juices of the corn plant. A few others of somewhat like character are known to injure the crop, especially during certain seasons unusually favorable to their development.

But we are to write of quite another thing. We hear much nowadays of "disease germs." It has been positively ascertained, and is now generally accepted as an incontrovertible fact, that the communicable diseases of animals (including man), that is, those which are transmissible from diseased to healthy individuals, are due to living organisms. These gain entrance in some way to the body, rapidly multiply in number, take their nourishment from the normal stores of the animal, and usually cause therein injurious chemical changes. By far the largest number of these disease agents belongs to the group of exceedingly minute plants called bacteria—a word with which all are now familiar, though those who have not had the opportunity of seeing them under a compound microscope of high power may not have a very definite idea of the organisms themselves. An individual among them consists of a single cell, which owing to its exceedingly minute size can not be very well studied as to its further structure. It is, however, known to consist of an outer membrane or wall with contents of a different character. There are no organs or members of any kind, save that some varieties have issuing from one or both ends of the miniature body a hair-like projection capable of rapid vibratory motion by which the little individual swims in the liquid in which it is immersed. Food can be taken only in the liquid state, by absorption through the exterior wall. Multiplication takes place by a single cell becoming transversely divided and the two parts enlarging so as to form two cells, each of which is exactly like the original one. In all cases the two young cells may at once separate, but in the case of certain species they commonly remain attached so as to form a necklace-like string, or, with certain others, in little squares with the individuals in rows both ways. Some kinds produce "spores." The contents of a cell collect in

a definite manner in the middle or at one end of the cavity, become considerably condensed, and form about themselves a special wall of their own. Subsequently the wall of the original cell decays or becomes dissolved, freeing the internally formed spore. These spores, owing to their greater density and consequent stronger refraction of light, have a glistening appearance under the microscope. They are able to withstand injurious substances and degrees of temperature far beyond that of the vegetating cells in which they are produced. Under proper conditions they may germinate, each forming again a cell like that in which it was formed. This is the simple story of their life. There is no sexual or other differentiation among the individuals. Any one may become two by dividing, as described; and, as this process can take place under favorable circumstances in a very short time and be constantly repeated in similar manner, the number of individuals increases in geometrical ratio and soon becomes enormously great. It is on this account that the little things, insignificant as individuals, become irresistible agents of destruction. When disease is "caught" from one previously infected, it is due to the transfer of some of these living atoms capable of originating a myriad progeny in the previously healthy body.

Compared with the number of communicable diseases due to bacteria affecting animals, there are few known in the vegetable world, though some have been as definitely and conclusively established. Among the latter may be counted the so-called fire blight of apple and pear trees; a disease of hyacinth bulbs; and, without attempting to exhaust the list, a disease of broom-corn and sorghum, *the latter being very similar in characteristics and comparative amount of injury to that to be here described of Indian corn.

APPEARANCE IN THE FIELD.

The first indication of the disease in a field of corn as noticed in ordinary observation, is the dwarfed condition of the young plants. This commonly occurs in spots of various sizes from a few square rods to an acre or more, and often, though by no means always, on soil of character somewhat different from the rest of the field. It seems hard to designate what special condition or quality of soil is most usually associated with the disease; but, upon the whole, it is found in the rich spots rather than in those of poorer quality. In many cases it is upon the lowest ground, whether or not water has temporarily stood in the hollows. The most definitely bounded area noticed was upon a spot which had until the year previous been too wet for tillage but which had been tile drained and broken up, the sod having rotted. This was planted the following spring with the rest of the field and no part seemed to be in better condition for a heavy

* Burrill: Proceedings American Society of Microscopists, 1887.

" Proceedings Society for the Promotion of Agricultural Science, 1887.

" Report Board of Trustees, University of Illinois, 1887-88.

Kellerman and Swingle: First Annual Report, Kansas Experiment Station, 1888.

crop. The season (1887) was quite dry, and there was at no time subsequent to the planting any superfluous water in the area described. The seed germinated and the young corn grew satisfactorily until after the second plowing when the plants were more than six inches high. Then the newly tilled spot showed, by the change in the appearance of the corn, in a very definite manner, to the very furrow on the margins, a distinct difference from the rest of the field. The corn ceased growing, became yellow and unusually slender, then for the most part died. Careful examinations showed that the trouble was not due to insects, but to the immediate agency of the bacteria described below. The destruction was so complete that the spot was replanted, and, singularly enough, this time grew to large size though more or less diseased. A few stalks of the first planting after a time seemed to recover from the malady and for a long time showed high above the younger growth. But ordinarily there are no such definite borders to the infected areas, and often nothing whatever to suggest a reason for their peculiar distribution. It may be stated here that later in the season, after the tassels have appeared, the disease may be found widely scattered throughout the field, affecting only here and there a stalk or hill, while the rest remains free from it.

Upon closer observation it is found that young diseased plants, besides being smaller than the healthy ones, are uniformly yellowish in color, the lowest leaves showing worst. As death overtakes these leaves, they apparently succumb by a general decline from the healthy state, and rarely die and wither chiefly at the ends and margins as in some other cases. When some of the affected plants are pulled from the ground, they are found to give way too easily in consequence of the death, to a greater or less extent, of the oldest and lowest roots. In anything like severe cases at least one-half the roots—always the lowest—are injured and usually dead. The bottom portion of the stalk is likewise affected and will be found dead or dying. If split longitudinally through the middle, the inner tissue of this lower part is seen to have a uniform dark color; and a similar discoloration, gradually becoming less and less pronounced, appears in the next succeeding nodes or joints, while the spaces between them (internodes) are seemingly healthy. On the surface when carefully freed from dirt, brownish, corroded spots can be found, sometimes strictly bordered, again diffusely spreading. Sometimes masses of semi-transparent, rather firm, gelatinous material are found upon these external corrosions.

After midsummer, especially, the disease becomes apparent through discolorations of the portions of the leaves called the sheaths, which closely invest the stalk. These leaf-sheaths become variously spotted as observed from the exterior. Sometimes the watery-brown portions are mere specks; sometimes large irregular patches, and of all grades between these extremes. The discolorations become brown, of a half-rotten appearance. Occasionally there is a little reddish color, more often bordering the brown. If now these affected leaves are stripped from the stalk, it

will be found that the evidence of injury is much more conspicuous on their inner side. The injured patches are larger, have a more watery appearance and sometimes are more or less smeared with the same gelatinous substance previously mentioned as occurring on the diseased stem below ground; but here on the leaf-sheaths it is usually spread in a thinner coating or layer, instead of in rounded masses. This infection of the leaf-sheaths evidently comes later in the season than the first noticed form of the disease on the roots. It seems also to be evenly distributed through the field and to occur upon large as well as small plants.

Finally, the ears are, at least occasionally, affected. Externally, the appearance of the outer husks is like that of the diseased leaf-sheaths. Internally, in the worst stage, the whole ear—husks, which should be still green, young cob and kernels, and the mass of “silks”—is reduced to a moist state of corruption, though not ill-scented. The parts lose their normal rigid or turgid quality, appear as if wilted, and are packed closely together, if not actually adhering by the gummy exudation from the tissues. Very often these ears subsequently become mouldy, penetrated through and through by a close, very white, felt-like fungus. Possibly this fungus sometimes makes its inroads into the ear without the bacteria as forerunners; but from present knowledge it seems probable that it is a secondary intruder. These mouldy ears are in certain seasons very numerous and are readily recognized by the husker, as well as by the buyer when the loads are sent to market.

HISTORY OF INVESTIGATION.

During the year 1882, Professor S. A. Forbes, while studying the work of chinch bugs on corn, sent me for examination portions of corn stalks and leaves, collected in McLean county, upon which were found the corroded spots above described, and, associated with these, the gelatinous substance above referred to. During this same time the chinch bugs were found to be infested with bacteria, which soon swept them all off by a veritable contagion. Since the bacteria-possessed insects were found on the corn and these lumps of jelly also full of bacteria along with them on the corroded leaf-sheaths (the injury was then supposed to be solely the work of the insects), notwithstanding the different appearance of the organisms under the microscope, the jelly was referred to in the published description of the chinch bug parasite* as *zoöglæa* masses. The statement was, however, shown to be doubtful by the insertion of an interrogation mark.

This is believed to be the first published reference—slight as this is—to the corn parasite with which we now deal.

At various times many examinations were made upon the roots of sickly corn in which there was no evidence of insect work, with the expectation of finding, if anything, the mycelium of a fungus. These once

*American Naturalist, 1883, p. 319.

and again proved abortive, and the conclusion was finally reached that no such parasitic growth existed in connection with the malady.

The next critical investigation of growing corn affected with the disease came about in a very similar manner. During several years preceding 1889, the chinch bugs were exceedingly numerous and destructive, especially throughout the southern portion of Illinois, and the state entomologist was earnestly endeavoring to collect all possible information concerning them and the peculiarities of their life history. At Albion, Edwards county, Ill., a field of corn belonging to J. Skeavington was found which presented so poor an appearance, without evidence of insect depredations, that in July, 1887, Professor Forbes brought home some of the plants for further study. Some of these were turned over to me for examination. The descriptions already given of the affected roots and leaf-sheaths might have been written from these stalks; and, furthermore, the organism was identified to which we now attribute the malady. Search was now made in fields near the University and the disease was found in progress. Studies were carried on during some weeks, the specific organism being invariably found associated with the affected parts; pure cultures were secured and inoculations made in healthy corn. The latter failed. On this account no publication was made of the facts obtained, it being thought desirable to ascertain positively the causative action of the bacteria before proceeding further. During the season of 1888, other things demanding first attention, no further studies were made upon the disease except to note its occurrence and distribution. A field of forty acres near Kankakee, Illinois, was found almost ruined by this disease. In this case the land was excellent in quality and in good condition, and the corn had been well cultivated. The seed had come up well, and for a time the growth progressed finely; but nearly all the stalks remained abnormally small; many gave no indications of earing and the best of them produced "nubbins" rather than ears. It was found here, as in some previous cases, that after the lowest roots had died and others had been put forth above the former, these later roots soon became diseased. Sometimes when the "brace" roots issuing from the stem above ground reached and penetrated the soil, they, too, became corroded, or sloughed off in a mass of brown mucilage, thus in effect destroying the plant. The characteristic bacteria were found present.

The next thing which drew renewed attention to the matter was the discovery by Dr. F. S. Billings,* of the Agricultural Experiment Station of the University of Nebraska, an acute observer and thorough-going pathologist, of a "germ" in cattle which had died after feeding upon corn stalks in the field, at Ames, Nebraska, January 6, 1888. Other cases occurred at different places in the state and received more or less attention until, finally, in the winter and spring of 1889, the distinguished investigator took up the subject for more special research. Having

*Original Investigations of Cattle Diseases in Nebraska, 1886-88, Bulletin of Experiment Station of Nebraska.

learned of my examinations of corn diseased in the fields, he asked me for a description which he included (page 199) in the volume referred to. He also sent cultures of the organisms obtained by him from infected animals for comparison with those taken by me from the growing corn. They seemed to be alike. In March I applied the Billings "germ" from a culture to some young corn which we happened to have growing in the greenhouse. Nothing came of this, though inoculations and smearings were made in several ways. Rabbits and mice, however, quickly succumbed upon inoculation. Some wild gray rabbits, which had been proof against the hog cholera "germ," died within six days after subcutaneous inoculation.

Finally Professor Forbes⁴ found, near Sycamore, Illinois, July, 1889, indications of this newly studied disease throughout considerable areas. He again brought in specimens and examination proved his suspicion correct. Soon afterward the writer visited the fields mentioned and many others through the northern part of the state. Of the places visited the disease seemed to be worst in the Sycamore region; but more or less evidence of it was found in numerous widely separated localities. At Sycamore some improvement had apparently taken place since the first named observation, the later roots appearing free from injury. But in certain fields a large percentage of the stalks showed no indications of earing and could not, it was thought, after that time (August 1st), produce anything like a satisfactory crop.

After receiving the first diseased plants from Sycamore, search was again made at Champaign, and the malady was found in several fields. Cultures and inoculations upon growing corn were made, and this time with unmistakable results. The bacteria, in pure cultures, were applied to the inner surface of the leaf-sheaths, without puncture, and the watery-brown spots appeared in four days while the organisms multiplied enormously in numbers and were taken still pure—in favorable cases—in considerable quantity from the affected surfaces.

Time has not permitted a large number of these experiments, and the results so far obtained do not warrant a conclusion as to the reason of previous failures in the greenhouse and out of it; neither have we, so far, satisfactory results from application to the roots and subterranean stems. But with the positive results from inoculation of the leaf-sheaths and the abundant evidence upon examination and culture, it cannot be doubted that the specific bacteria are the direct agents in the destructive work.

This is written August 16th. During the last ten days inoculation and feeding experiments upon a small scale have been tried upon rabbits without positive results. These tests are too few and too recent to be of much import here; but they do serve to show that the "germ," if the same as that in the experiments of Dr. Billings, has not now the virulence that his had either with him or myself. The identity of the two is therefore still to be proved.

THE BACTERIA.

As has been indicated above, the disease organisms in this case are found in great numbers on and within the affected parts of the roots, the subterranean stem, the leaf, and the ear. In many cases they collect on these surfaces in gelatinous lumps or masses which really consist, for the most part, of the organisms themselves held together by the stiff mucilaginous substance which they themselves exude. If a microscopical preparation is made directly from this jelly, it will be found that the individual organisms are quite variable in shape, though many of them are elongated, almost cylindrical, with somewhat tapering ends. The usual stains affect these little rods in a peculiar manner. One, or more, often two, dot-like portions take a deep color while the rest remains unstained. When these dots are near the middle, as is more often the case, the extremities usually become less and less visible, until it is only possible to make out the terminal portions with a good objective and excellent illumination. But mixed with these elongated forms are many of quite uniformly oval shape, very often joined two and two by their contiguous ends. These stain solid throughout, or are paler in a central transverse band. All variations occur from a very narrow pale central band up to a very wide one, and in the latter case only the tips of the ovals are colored by the dye. These peculiarities of staining are almost exclusively confined to the fresh substance as collected from the plants. When the bacteria have been grown in artificial cultures, they usually stain uniformly solid throughout, though occasionally pale-centered individuals are found. Upon first examination, any observer would at least suspect that the oval and elongated forms described were different species; but cultivation tests show that both belong to one and the same thing, and in all artificial media tried they are always quite or nearly oval in shape, though often differing considerably in size after the culture becomes more than eighteen to twenty hours old.

They divide in one plane only, in the direction of the short axis. It is very common, especially when they are rapidly growing, to find them in couples; but they rarely adhere in strings of greater numbers. They multiply rapidly at the ordinary temperature of the laboratory, but seem to grow fastest at about 36° C. (97° F.). It should be said, however, that, though the recent work was done in midsummer, the room—in the basement of a large building and on the north side—was always cool enough for comfort.

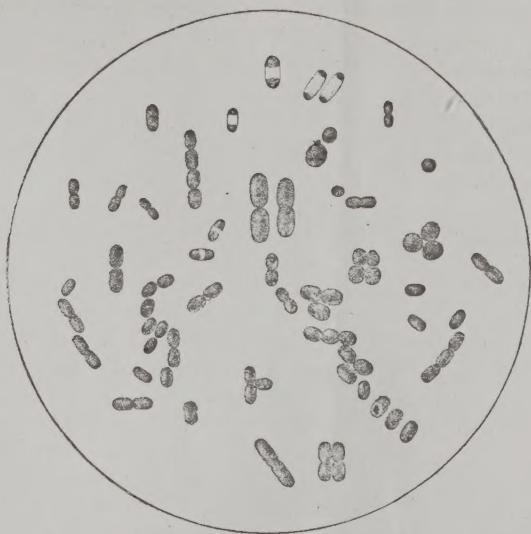
In notes made upon the organisms in 1887, they were said to have swimming movements in fluids; but in the examinations made in 1889, such movements have not been detected, though trials were made from fresh liquid and solid cultures, in beef broth and in water, at the ordinary temperature of the room and warmed upon the stage to 36° or 37° C. However, these trials were only made a few days before this writing and may not indicate the full truth. This peculiarity of movement differs greatly according to conditions, though certain species never possess it.

Nutrient gelatine is not liquified. In a "stab" culture in this medium there is to be seen along the needle tract after twenty-four hours, a grayish streak, which becomes slightly diffused by minute lateral ramifications into the substance, the borders not being very definitely marked. But the spreading does not, with more time, long continue; hence the line does not become more than an eighth of an inch wide. On the surface the growth spreads in a definitely bordered circle, commonly somewhat wavy, and is lusterless. On the sloping surface of an agar tube the growth is prompt and characteristic, forming during twenty to thirty hours at 36° C. an opaque, lusterless, white streak with margins nearly even or regular. On examination with a lens, it can be made out that the mass is not entirely homogenous. There are obscure rays of more or less opaque character, sometimes giving a slightly feathered, often a simply mottled, appearance. If the medium is quite moist, the pasty mass at length runs down and collects at the bottom of the tube. The growth never becomes diffused in a film over the surface. In liquids the tube becomes uniformly turbid within twenty-four hours, plainly more so in the incubator at the temperature named. At the end of this time, though not much before, there appears on the surface a thin, fragile pellicle which readily breaks up on handling and slowly settles to the bottom. No spores are formed.

In fresh cultures of beef broth the ovals average a little longer than they do when grown on solid media. On quite moist agar, the two diameters of the individuals in a culture eighteen hours old differ but slightly and the shape is very uniform. The transverse measure, however, in all fresh cultures is very nearly uniform and is about .65 micron (.00026 in.). The most common length of a newly divided pair is 1.6 micra; each individual being about .8 micron.* Single ones average a little longer and occasionally reach the length given for a pair.

* A micron is one-thousandth of a millimeter, or about one twenty-five-thousandth of an inch.

FIGURE SHOWING FORMS OF THE BACTERIA, MULTIPLIED 3,333 TIMES.



Description of Figure.—The figure is a photo engraving from a drawing by A. M. Westergren, under a Tolles' $\frac{1}{15}$ -inch homogenous immersion objective, with a Huguenian eye piece furnished with a Rogers micrometer. The instrument magnified, as used, 1,650 times (diameters). Lines were drawn on the paper corresponding to those of the micrometer, so as to make the magnification exactly 5,000 times. Reduction of one-third was made in the engraving, so that the representation, as it now appears, is 3,333 times the natural size. In making the drawing there were used three slides from cultures each of which was known to be pure, and one slide made directly from the gelatinous substance on a leaf-sheath. The endeavor was made to select from these four slides all forms and sizes of the organisms which they contained and thus to show, as nearly as possible, all the variations of the species. Every individual figured was drawn as accurately as possible from the actual object. Methyl-violet stain was used.

The typical form is represented by those of medium size having an oval shape, most numerous shown. The largest ones are indicated by the two near the center of the figure, and the peculiar appearance of those not becoming uniformly stained is shown near the top. The two, near together, with dark color near the ends only and a much paler but somewhat colored central area, are types of those obtained from mounts made directly from the diseased plants. The seemingly perfectly spherical forms are supposed to be standing on end, though there is some doubt in regard to the largest of these. The greatly elongated forms with central dots are not shown in the figure.

REMEDIAL TREATMENT.

We know too little of the disease to be able to suggest a remedy. In the studies made during the last two weeks especially, there appears to be in a considerable number of cases more injury on land which has been planted with corn the preceding year, though the rule does not always hold good. In one case the worst results followed when timothy sod had

been broken up and corn planted thereon; while a timothy pasture not far distant, treated in the same manner gave a thoroughly healthy crop of corn. Grass and weeds have been carefully examined without finding indications that the same disease affects them. Probably the bacteria live over winter in the soil, though we have no experimental data for this opinion. If this is a fact, then young corn would be liable to suffer when growing upon land on which the preceding crop was diseased. When it is definitely known whether anything besides corn is affected, we shall be better able at least to theorize upon a cure.

From observations now made it appears that the disease is a very prevalent one and, probably, has existed during the time that corn has been grown on the continent. If so, it has not ordinarily attracted attention and, very likely, is not destructive enough to be specially noticed. When, however, under peculiar circumstances, the crop is injured to the extent now sometimes known, the loss is very great, not only to individual farmers, but to the country at large.

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All communications intended for the Station should be addressed, not to any person, but to the

AGRICULTURAL EXPERIMENT STATION, CHAMPAIGN, ILLINOIS.

The bulletins of the Experiment Station will be sent free of all charges to persons engaged in farming who may request that they be sent.

SELIM H. PEABODY,
President Board of Direction.